Using Thermodynamics to Improve Bat Houses in Cold Climates

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Abstract

Wildlife managers design artificial structures, such as bird and bat houses, to provide alternative habitats that aid wildlife conservation. However, prototypes may not be equally efficient at all sites due to varying climate or habitat characteristics influencing thermal properties. For example, bat houses are a popular measure employed to protect bats and educate citizens, yet bat houses have achieved limited success in cool climates. To address this problem, we tested different orientations and mountings for both traditional and newly designed bat house models based on modern architectural energy saving concepts, by recording temperatures in bat houses across a climate gradient in Quebec, Canada. Bat houses mounted on buildings had warmer conditions at night than those on poles and warmed sooner in the morning when facing east. Our new insulated model with passive heating maximized the time in the extended optimal temperature range (22 – 40 °C) of targeted species by up to 13% compared to the Classic model, providing bats with an estimated average daily energy savings of up to 7.8% when mounted on a building. We conclude that the use of energy-saving concepts from architecture can improve the thermal performance of wildlife structures.

Introduction

Artificial roosts for wildlife can help mitigate threats to animal conservation associated with habitat loss, climate change and direct human disturbance. Artificial roosts can be used to supplement available habitat, compensate for habitat lost, provide reproduction or nest sites, protect prey from predators, or shelter species from adverse weather[1–5]. Apart from direct conservation, artificial roosts can also facilitate the study or monitoring of wildlife populations[1], as well as enhance citizen education and stimulate public involvement toward conservation[6]. Many investigators have reported the occupancy rates of artificial roosts, but few have explicitly studied the underlying causes influencing the selection of some models over others[7–9]. To avoid artificial roosts becoming ecological traps, it is important to understand how design, location, and mounting influence the microclimate, and ultimately, the preference and health of animals[10–12]. For example, microclimate may vary among sites and can affect the energy budget of individuals, especially at critical life cycle stages, such as migration or reproduction [13–15].

Wildlife living in seasonal environments must adapt to a wide range of temperatures. For insectivorous species, the negative effect of ambient temperature on food availability compounds this problem[16]. Torpor is one strategy used by insectivorous bats to cope with the costs of maintaining a high body temperature[17,18]. Although beneficial to sync development or allow bats to save energy on cool days when insects are not available, entering torpor during summer may also delay female reproduction by slowing fetal development and reducing milk production[19–21], with negative consequences on the probability of survival throughout hibernation for both mother and offspring[17,18,22,23]. To reduce torpor use and optimize their fitness, female little brown bats (*Myotis lucifugus*) inhabit warm roosts close to feeding sites (home range within 20 – 30 ha [24]). The thermoneutral zone of little brown bats is 32 – 37 °C[25,26]. When roost temperature falls below 20 °C in gestation, or below 22 °C in lactation, females use torpor 50 – 70% of the time[27]. On the other hand, when temperature reaches 40 °C, individuals were found to move from upper to lower areas of attics most likely to avoid detrimental effects of overheating[27,28]. Selection of warm maternity roost sites with favourable temperature ranges is crucial for breeding females to reduce energy expenditure while maximizing reproductive success[13–15].

North American insectivorous bats are important pest consumers, yet more than half of those species are declining under anthropogenic pressures, exacerbated more recently by exposure to White-Nose Syndrome (WNS)[29,30]. Bats have long life expectancy and reproduce slowly, which makes population recovery slow[31]. As bats spend over half of their lives within roosts[32], providing suitable roost sites can be one step toward population recovery. Experiments have occurred since the 1980s to test bat house effectiveness as conservation measures. Bats select roosts based primarily on microclimate[8,28,33–35], which is itself influenced by many factors, including bat house orientation, mounting, sun exposure, colour, design, construction material, and the number of occupants[28,35]. Proximity to water, species-specific habitat type, proximity to an existing roost site, time since installation and clustering of bat houses increase the probability of bat house colonization[7,36]. Colonization success also rises when using multiple narrow chambers that allow bats to roost side-by-side and employing an open bottom design that reduces colonization risk of non-target species (e.g. birds, small mammals, wasps) and feces accumulation[7]. Finally, preferred height above ground, form and size vary widely among regions and species[7,36].

Despite these potential improvements, bat houses have achieved only mixed success[7,36–38]. Colonization rates vary widely from 0 – 100%, with low rates for maternity colonies in cold climates[8,36,39,40] (but see [41]). Most studies on bat houses occurred in temperate and warm regions, such as the United States and the Mediterranean, and few researchers have adapted bat houses to colder conditions[35,41,42]. Recent progress on passive solar architecture, used to heat or cool residential houses, could be transposed to wildlife artificial roost development to create better-adapted microclimates and more versatile artificial bat houses. Passive solar designs take advantage of a building's site, orientation, climate and materials to minimize energy use for heating and cooling to maintain a suitable microclimate. These designs reduce heating and cooling loads through energy-efficient strategies, such as using thermal masses to store the heat, which are redistributed through radiation during the night[43].

The present study aimed to improve the thermal properties of artificial bat houses by testing different models, orientations and mountings to meet the thermal requirements of reproductive *Myotis* females living in Quebec. We expected that external factors, such as an east-facing orientation and mounting on a heated building, could improve thermal properties of bat houses and favour the extended optimal temperature range (EOTR) of reproductive female *Myotis* (22 – 40 °C). We also expected that integrating concepts of energy saving and passive heating into bat house models, as used in human building construction, would improve the thermal properties and increase the amount of time within an EOTR of 22 – 40 °C compared to traditional models. Finally, we expected that thermodynamic improvement of bat houses should lead to lower modelled daily energy expenditure, especially at night and in the morning, when reproductive females are thermally challenged as they rewarm after nightly torpor bouts.

Materials And Methods

In 2017, we tested the effect of orientations and mounting types on two sites. At each site, classic 4-chambers bat houses with no vents (https://www.batcon.org/wp-content/uploads/2020/09/4-Chamber-Nursery-House-Plans.pdf) were mounted on a heated building, a non-heated building, and on poles. We mounted these houses facing east, south, and west for the building mountings and east, south-east and south for pole mountings for a total of 9 bat houses per site (Figs. 1, 2). From 2016 to 2018, we tested many current models as well as an iterative series of new models (presented in Supplementary Table S1: European 1-chamber, Insulated rocket, Solar-heated insulated rocket, Rocket PH2, Biclimate.0, Biclimate, Classic PH1 and PH2, and Ncube PH2.0 and PH3.0 (on building and on pole versions)). In 2019, we compared the classic model to the best new model, the Ncube PH1 (Supplementary Fig. S1-S4) on seven sites separated into cold (n = 2, $T_{\bar{x}\text{ in June}}$=11 °C), intermediate (n = 3, $T_{\bar{x}\text{ in June}}$=16 °C), and warm sites in Quebec (n = 2, $T_{\bar{x}\text{ in June}}$=19 °C). The two warm sites and two intermediate sites had pole and building mounting, the other sites had either pole or building mountings (Fig. 1). At all sites, the area around bat house sites was free of trees or any object causing shade. We installed bat houses at the same heights (3 – 4 m high) and orientations (east) for all model-comparison tests. Four criteria guided the elaboration of the newly designed models: 1) thermal preferences and requirements of little brown and northern long-eared bats minimizing torpor use: EOTR of 22 – 40 °C (Henry, 2001), 2) a passive heating design, 3) a relatively light weight, and 4) a low cost. The last two criteria were selected to facilitate large-scale implementation of an improved model to help endangered *Myotis* species. All bat houses were black. Newly designed bat houses were conceptualized based on principles used in passively heated houses, including greenhouse effect and insulation. We also reduced the entrance width to reduce heat loss. Design of the bat houses was developed via a collaboration among biologists from the Ministry of Forests, Wildlife, and Parks and McGill University, engineers from Transition Energetic Quebec, and architects from Ncube/CCM2.

From mid-May to mid-September, we recorded bat houses external and internal temperature for a total of 122 days and 52,704 temperature data points per experiment (i.e. orientation, mounting, and design tests). We used external temperatures (T_{ext}) from either an *in situ* meteorological station or the nearest Environment Canada station (maximum distance = 1 km; Supplementary Table S2 for the name and location of the station used). We recorded internal temperatures (T_{int}) every hour using iButtons (https://www.ibuttonlink.com/products/ds1921g). As bats tend to stay at the top of bat houses, iButtons were placed in the top quarter of each bat house (one in the third chambers from the front in the classic and two in the Ncube PH1 in the main and lower chambers). Bat houses were monitored at least every month to verify the presence of bats in houses (monitoring; guano, bat sighting or hearing) to ensure it did not affect the internal temperatures of bat houses. During the four years of monitoring, no colony inhabited the bat houses and we detected only one individual in two different bat houses. The occasional presence of individual bats would not change the overall internal temperature profiles of the bat houses as those individuals were likely males or non-reproductive females that often use torpor to save energy[44–46]. Furthermore, we carefully investigated the data for signatures of anomalous increases in temperature indicative of bat presence and we did not find any such signatures.

We evaluated the quality of experiments (orientation, mounting, and model) based on the thermal properties defined as the percentage of time below, between and above EOTR, and minimal and maximal internal temperatures ($T_{int-min}$, and $T_{int-max}$). To compare non-linear daily temperature profiles and evaluate differences among treatments, we used general additive mixed models (GAMMs). We tested differences among orientations for classic models by including bat house T_{int} facing south, south-east, east, and west as response variables, orientation, time, date, T_{ext}, and structure as fixed effects, and location and bat house id as random factors. We modeled differences among structures for classic models by including bat house T_{int} mounted on poles, heated, and non-heated buildings as response variables, structure, time, date, $T_{ext,}$ and orientation as fixed effects, and location and bat house id as random factors. We evaluated differences among bat house models by including bat house T_{int} according to their design as a response variable, time, week, T_{ext}, and structure as fixed effects, and location and bat house id as random factors. Because of the high daily variance in the design dataset, we used mean hourly temperatures over 14 days instead of every day to reduce confidence intervals, which helped to detect differences among bat house models (see Supplementary Table S3 for statistical model descriptions). We divided time between day (7h00 – 18h00) and night (18h00 – 7h00). We chose these two periods as bats are more likely to be in the roost during the day and away at night and they corresponded to periods when temperature dropped (night) or rose (day). We used a significance threshold of ≤ 0.05 for all tests.

Bioenergetic modeling

Reproductive female bats select roosts that reduce energy expenditure, increase time spent in normothermia and facilitate torpor in the early morning[47,48]. We used bioenergetic models to predict energy expenditure of little brown bats in Classic and Ncube PH1 models, based on their respective T_{int} and T_{ext} recorded at warm, intermediate and cold sites. We assumed that once temperatures reached 40 °C or higher bats would systematically select the coolest space. Therefore, we selected the T_{int} of the Ncube PH1 main chamber when equal or lower than 40 °C and the lower chamber (the “veranda”) when above 40 °C. T_{int} of the classic was based on the middle chamber at all times since external chambers acted as insulation, reduced overheating during the day while similar to the other chambers during at night (Supplementary Fig. S5).

We estimated daily energy expenditure during gestation and lactation periods based on the reproductive phenology, activity budgets, foraging flight costs, mean torpor duration per day and typical diet of the little brown bat in Quebec[15,27,48,49]. We calculated daily energy expenditure (Table 1; converted into kJ h^{-1}) from the sum of 1) normothermic energy expenditure (E_{norm}), 2) energy expenditure during torpor (E_{tor}) including cooling and torpor phases, and 3) energy costs of active arousals from torpor (E_{ar}). We then added the energy expenditure for foraging flights (in kJ h^{-1}) to the estimates. After assessing for data normality, we used a Welch’s paired t-test to determine if there was a significant difference in daily energy expenditure between the Classic and the Ncube PH1 2019 during gestation and lactation at warm, intermediate, and cold sites using a significance threshold of ≤ 0.05.

Results

Mounting and orientation

The daily estimated temperature of the Classic 4-chambers varied among mounting types, orientation and with time of day (Figs. 3, 4, Supplementary Table S4-S7). At night, the bat house temperature was between 1 – 1.5 °C warmer mounted on a building than a pole while the opposite occurred during the day (Fig. 3). On buildings, west-facing bat houses were significantly warmer in the early evening and colder in the early morning than those facing east. During the day, temperatures in east-facing bat houses were significantly different those facing south or west, being warmer especially in the morning (Fig. 4). On poles, the only significant difference was at mid day, when south-facing houses were warmer than those facing east.

Design

Daily estimated temperature varied among bat house models (Fig. 5, Supplementary Table S8-S9, see Supplementary Fig. S6 for all models). For comparative purposes, we present the EOTR for buildings at intermediate sites; results at warm and cold sites being similar with a higher and lower mean temperature respectively (Table 2, see Supplementary Fig. S7 for all models). Temperatures of the Classic 4-chambers and Ncube PH1 were significantly warmer than the outside temperature during both night and day. The Classic was slightly higher than the outside temperature (up to 2°C ± 1.5°C) during nighttime, while much warmer during daytime (up to 9°C ± 1.5°C). This model was in EOTR 46% of the time and above EOTR 2% of the time. The Ncube PH1 was significantly warmer than the Classic during both night and day (up to 4.5°C ± 1.5 °C and 3°C ± 1.5 °C respectively). Considering the bats can use the lower chamber when above 40°C in the main chamber, the Ncube PH1 was in the EOTR 58% of the time and never above the EOTR, therefore increasing by 12% the amount of time in the EOTR compared to the Classic.

Bioenergetic modeling

Predicted average daily energy expenditure was reduced by 3.2 – 7.8% during gestation in the Ncube PH1 compared to the Classic bat house model (Fig. 6). During lactation, energy savings varied between 5 – 7.4%. Energy saving differences were higher in colder sites compared to warmer sites but were significant at all sites and reproductive periods, except during gestation at warm sites.

Discussion

Many bird, bat, and rodent species prefer artificial roosting structures over natural ones[4,50,51], leading to higher population densities or population growth rates[52–54]. However, to be a valuable conservation measure, artificial roosts must be optimized and adapted to the species' needs and location. At our study sites, an easterly orientation and mounting on a building improved the thermodynamics of bat houses, likely favouring the reproductive success of little brown bats: it increased temperature at night and in the morning, reduced overheating events, and provided better thermal stability. The concepts of passive heating, inspired by human building construction, improved the thermodynamics of our newly designed Ncube PH1 model over the Classic model by increasing the amount of time within EOTR by 7 – 13% and remaining on average 4.5°C warmer at night. Finally, we confirmed that thermal improvements of bat houses could minimize the energetic costs and decrease daily energy expenditure. Average daily energy expenditure differences were greater for lactation than gestation period and at colder sites than warmer sites, with an average saving up to 7.8%.

Mounting

Few studies have evaluated the effect of artificial roost mount location on roost use[36,55], and none of them evaluated how mounting type influences the thermodynamics of the house. On our study sites, mounting on a building, heated or not, resulted in warmer temperatures than on a pole during the night with the reverse during the day. Solar exposure (from sunrise to sunset) lasted longer for bat houses installed on poles than buildings, as the latter were shaded for part of the day. Although warm bat houses are generally advantageous for bats, many bat houses on poles remained above the critical temperature of 40 °C on hot summer days at our warm sites, despite the potential for convective cooling by wind. Buildings protect bat houses from the wind and enhance heat retention, providing more stable conditions than those on pole in our study area. We detected no difference between heated and unheated buildings, day or night. The non-heated buildings tested in our study were brick or insulated buildings, so perhaps if we had tested non-insulated buildings, such as old barns or sheds, we would have obtained different results. Trees are also common mounting structures for bat houses but were not included in our study because they have low and slow occupancy rates compared with poles and buildings[40,56–59].

Orientation

Several studies report that the orientation of bird and bat houses influences occupancy rates, with south or east-facing houses being favoured in temperate and cold climates[59–62]. Few investigators have explicitly examined whether nest orientation preference appeared correlated with bird nest temperatures[62–64]. For bats, although Brittingham and Williams (2000) found that little brown bats established maternity colonies in artificial roosts that received ≥ 7 hours of sunlight, we are aware of no study linking orientation with internal temperature profiles[8]. In our study, the effect of bat houses orientation on its temperature depended on the mounting type, the influence being stronger on buildings than on poles. On buildings, bat houses facing east warmed sooner in early morning. Moreover, an easterly orientation enhances the time in the optimal temperature by almost two hours a day compared to a westerly orientation. Estimated temperature values for south-facing on buildings were surprisingly lower or equal to those recorded in the east or west, although they likely benefited from longer solar exposure at the warmest period of the day. Even if we have no empirical evidence, we suspect that roof eaves facing south and north created shade for a significant amount of time. Orientations tested in this study had little influence on bat houses temperature when mounted on a pole without differences in temperature increase in the morning. At night, we suspect insufficient heat retention on poles, while during the day, one side is always fully exposed to the sun. We argue that an east-facing orientation is generally preferable in areas with cold temperate climate as in Quebec. An east-facing orientation is especially helpful on buildings to maximize the time in the EOTR while minimizing the risk of overheating during mid-day.

Design

Design of artificial structures is a central variable to attract bats or birds and design refinement have been shown to improve the frequency use of nest and bat boxes[7,65,66]. However, although Mering and Chamber (2014) identified more than 48 type of bat houses varying in their materials, size, and shape, only a few studies succeeded to explain how structural characteristics of a bat roost influenced its microclimate[36]. In Portugal, temperatures of artificial roosts painted black (vs. white or gray) were most comparable to building roosts and had the highest use by bats[28]. In the USA, the “rocket” box was the largest roost and remained within the critical temperature thresholds the greatest proportion of time[67]. In Australia, Rueeger (2019) found that bat house colour, chamber sequence, construction materials, and vents influenced internal temperatures[7]. In Canada, bats preferentially selected bat houses with heating mats that controlled internal temperatures [15]. We also tested a solar-heated bat house, but this model required a costly and complex solar system, and the capacity of the battery constrained the function of the heating mat to only two hours per night. Therefore, we only recommend heated bat houses when electricity access is available. However, further study is required to fully understand the impact of heated houses in the wild with changing environmental parameters such as weather and food availability.

The Ncube PH1, which employed energy saving concepts, similar to those used in residential housing, improved thermal performances both on poles and buildings. We obtained the best thermal performance with our new model including: 1) a passive heating zone that creates a greenhouse effect improving the heat retention of the bat house, 2) a thick insulation to buffer against temperature fluctuations, 3) a reduced chicane entrance that buffers against temperature fluctuations and decreases heat loss, and 4) an additional cool chamber ("veranda") at the bottom, where bats can easily and safely go when the main chamber overheats. The elaboration of such a design was achieved thanks to the transdisciplinary collaboration of bat scientists (biological/ecological knowledge), architects (knowledge of material properties) and engineers (knowledge of thermodynamics). While translating energy saving concepts from human eco-housing to bat houses, we created a versatile passive heating design well adapted to a wide range of temperate and cold climates. The Ncube PH1 can easily be installed by two people with basic tools. However, while prioritizing the optimization of the thermodynamics of the bat house, we failed to keep a low cost (~ 500$ including carpenter time fees). Moreover, at warmer sites, the Ncube PH1 on buildings spent 1% of the time above 40 °C. We suggest three different ways to reduce overheating of the Ncube PH1 at warmer sites depending on the specific environmental conditions of the site: 1) a modification of the passive heating zone, from fully juxtaposed with the main chamber to a halfway position, 2) a wider entrance, or 3) a lighter colour.

Bioenergetic modeling

Roosts have the potential to influence energy expenditure considerably[68] through thermoregulation and/or passive rewarming from daily torpor[69,70]. This is especially true for reproductive females that select warm roosts and use shorter and shallower torpor bouts to cope with reproductive constraints[8,35,48]. A warmer temperature at night and a quicker increase in the morning mean potentially less time in torpor or lower energy costs of rewarming after torpor bouts. That time and energy savings can be transferred to gestation and milk production. A warm roost also enhances offspring growth[4,71]. Female bats using the Ncube PH1 2019 rather than the Classic model would save between 5 – 7.4%, with the highest saving at cold sites, underlining the importance of efficient bat houses adapted to cold climates. Some parameters, such as time in torpor, are flexible and depend on weather, sex and reproductive status[72]. Furthermore, the number of bats in a house will also influence individual energy expenditure[73]. Nonetheless, our model estimates reflect the bioenergetic advantages of our newly designed model and fit those reported in the literature for little brown bats[15,49].

Conclusions

We recommend erecting bat houses facing east and mounted on buildings when not conflicting with human use. We also advise bat house designs that include characteristics similar to the Ncube PH1 that buffers against extreme temperatures and increases the time in the EOTR (see Table S1-S4 for the original design plan and batwatch.ca for the improved 2020 design plan). The "veranda", a cool open chamber at the bottom is also a good addition to any bat house model in case of overheating events. We tested the Ncube PH1 model across a wide temperature range in Quebec and demonstrated its optimality for female *Myotis* across cool temperate and boreal climates. Despite the versatility of the Ncube PH1, we still recommend the installation of a cluster of different bat house models and orientations, which offer opportunities for roost switching[74] and social interactions (e.g.[75]). Multiple bat houses also enable bats to choose houses that provide favourable conditions[7,76], which are likely to change depending on sex, reproductive status, season, and weather[7,72,77].

Bat houses with improved thermal properties, like the Ncube PH1, could be valuable for enhancing quality of bat maternity roost sites given that events of extreme weather are increasing worldwide[78–80]. As our new designed model follows *Myotis* requirements, the Ncube PH1 could be used where citizens exclude bats from their dwellings or as a tool to combat WNS by enhancing high quality habitats[15]. Nonetheless, assuring an abundance of natural habitats is always desirable for bat conservation, especially for tree-roosting species. When installing bat houses, we encourage local testing and careful consideration of the habitat, availability of suitable roosts in the environment, target species, species present in the local bat assemblage, structure and orientation. Since this study showed the theoretical value of our newly designed bat house, the next step is to test its colonization success and its functionality for bats on a larger scale. Insulated models could retain heat generated through social thermoregulation better than uninsulated designs, which should also be considered in future studies. Artificial structure optimization using human architecture concepts shows a great potential to improve conservation tools for other taxa like birds or other hollow-dependent mammals.

Declarations

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Author contributions

A.F. and A.S. conceived the experiments, A.F., A.S., J.D., and B.D. elaborated the new bat house designs. A.F. conducted the experiments and analysed the results. All authors reviewed the manuscript.int

Competing interests

The authors declare no competing interests.

Data availability

The datasets generated during and/or analysed during the current study are available in the Open Science Framework repository, https://osf.io/kh2zw/?view_only=0656ff50af394a81a842f0c42a2c2b44.

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Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

Figures

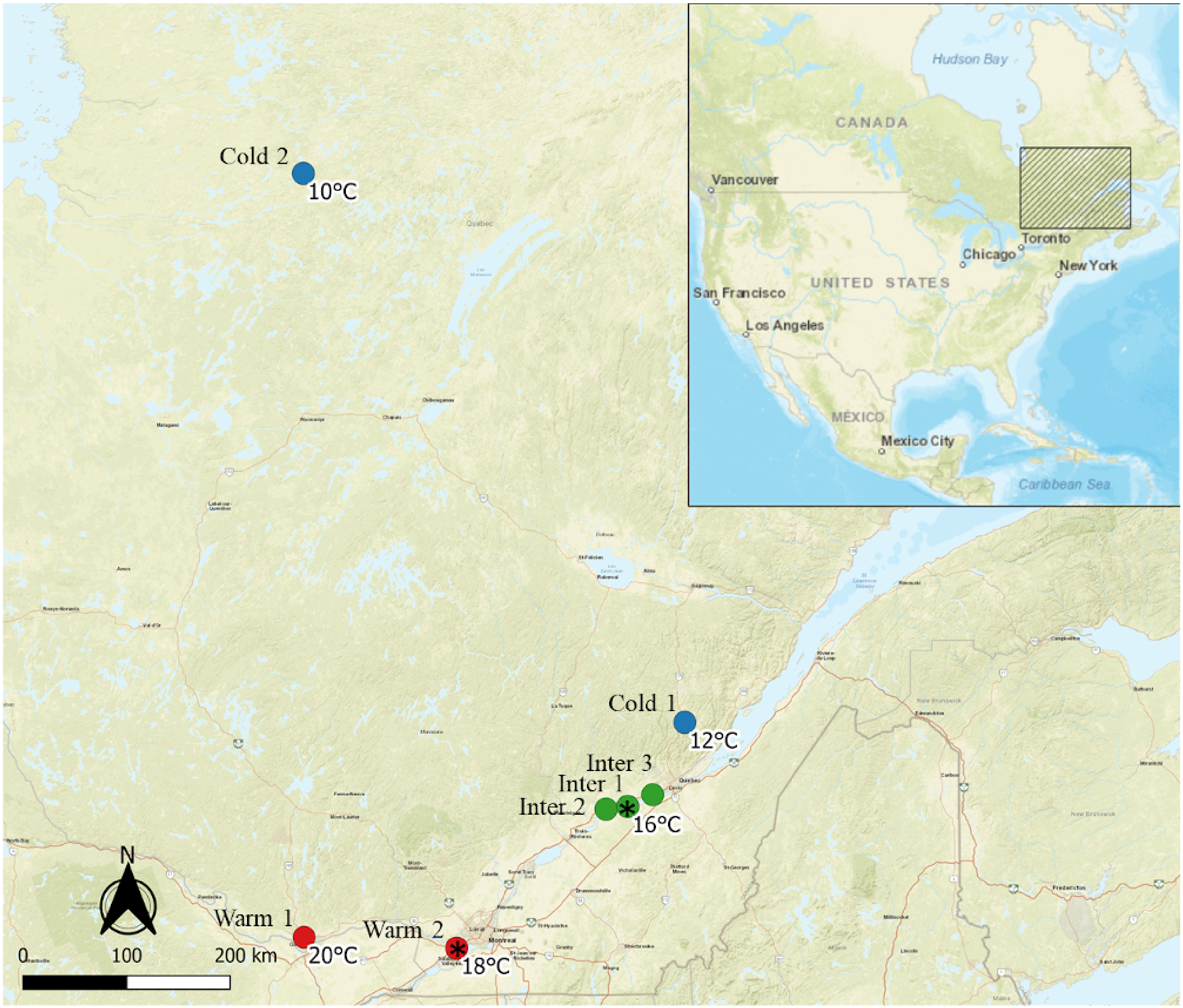
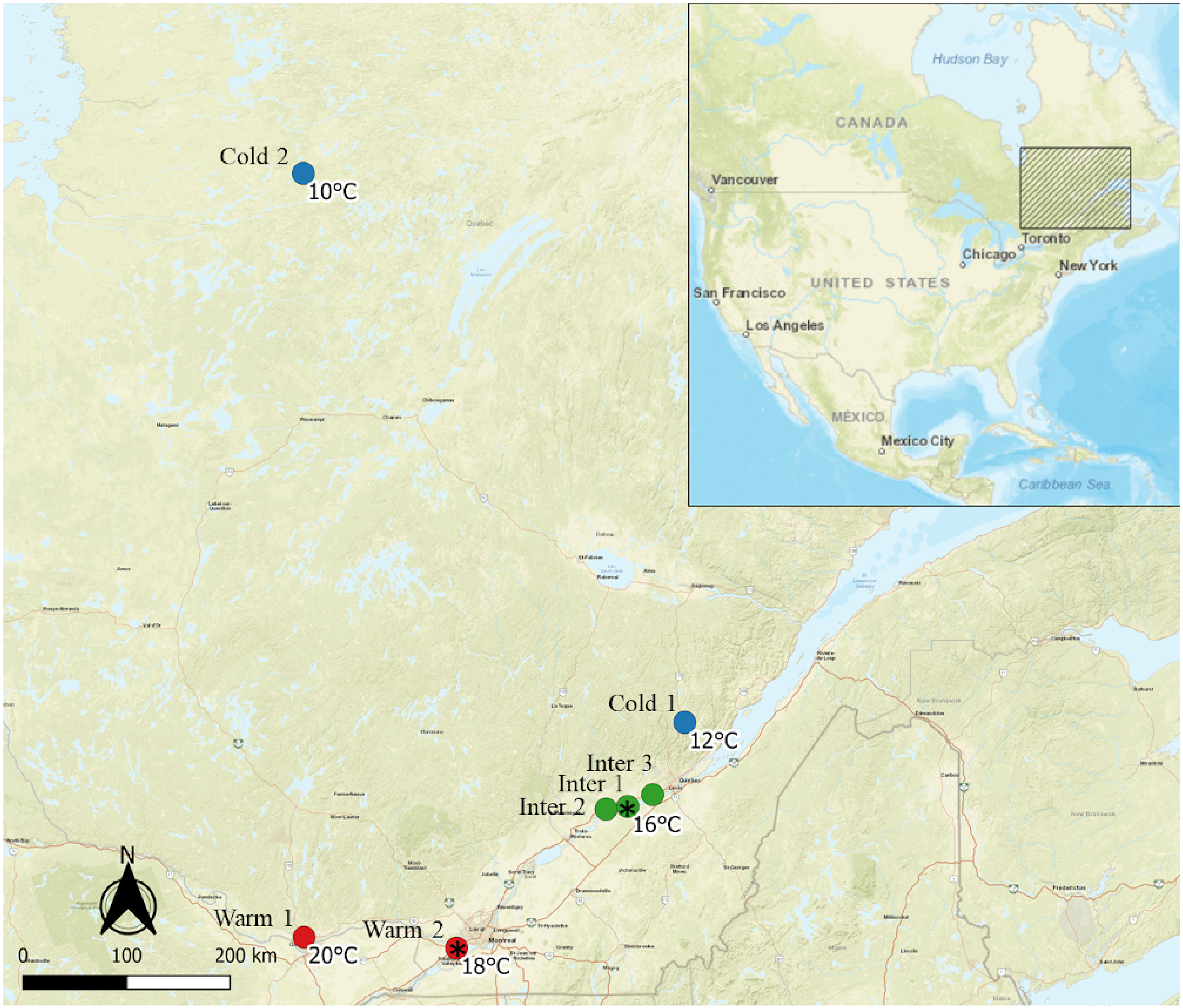


Figure 1

Location of the bat house installation sites at cold (blue), intermediate (green) and warm (red) sites in Quebec, Canada, from 2016-2019 with mean temperature in June. The Montmorency forest is considered a cold site due to its high elevation. Structure and orientation tests occurred at sites represented by a star.



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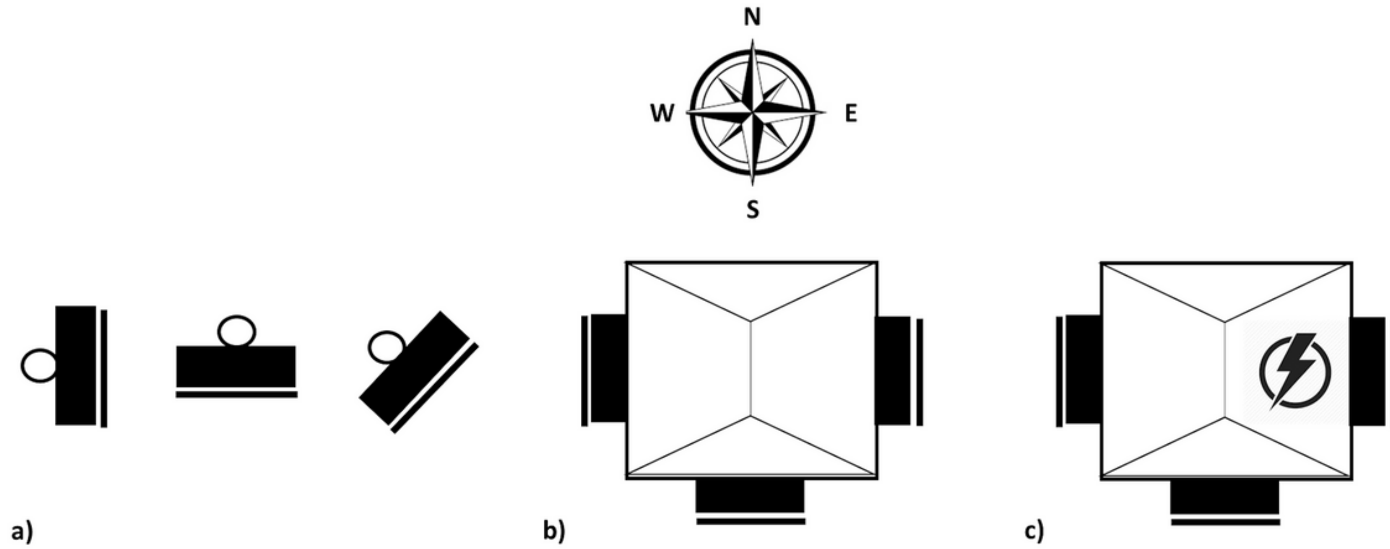
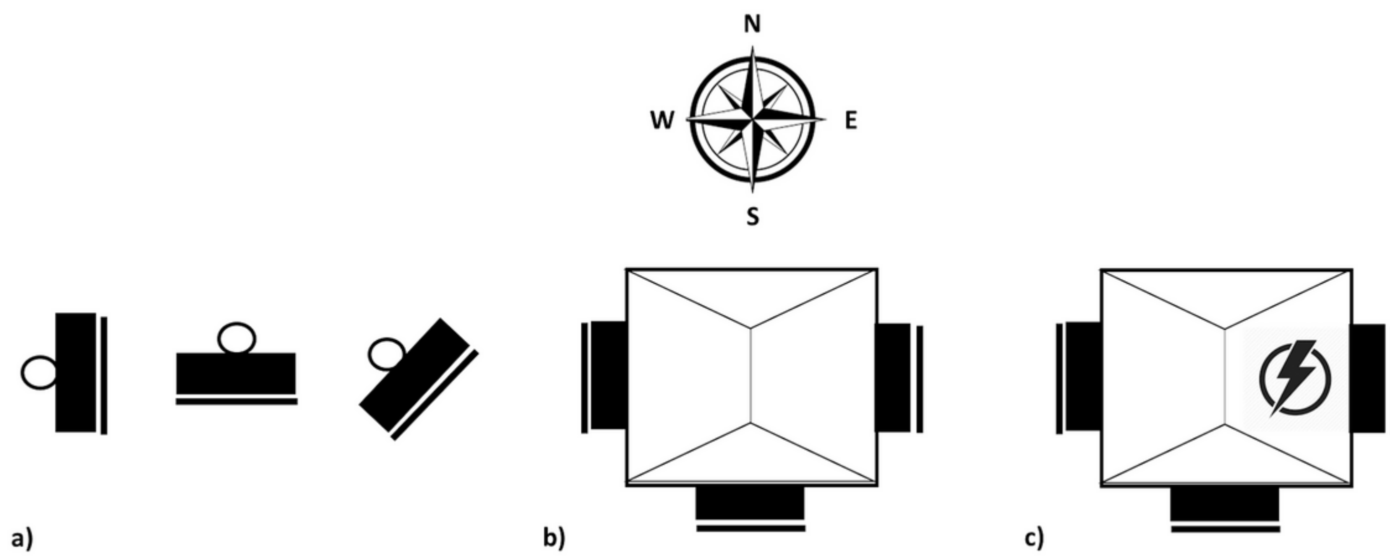


Figure 2

Schematic view of the experimental design for the orientation and mounting as tested for bat houses on two sites in Quebec, Canada in 2017 on a) poles, b) non-heated buildings and c) heated buildings.



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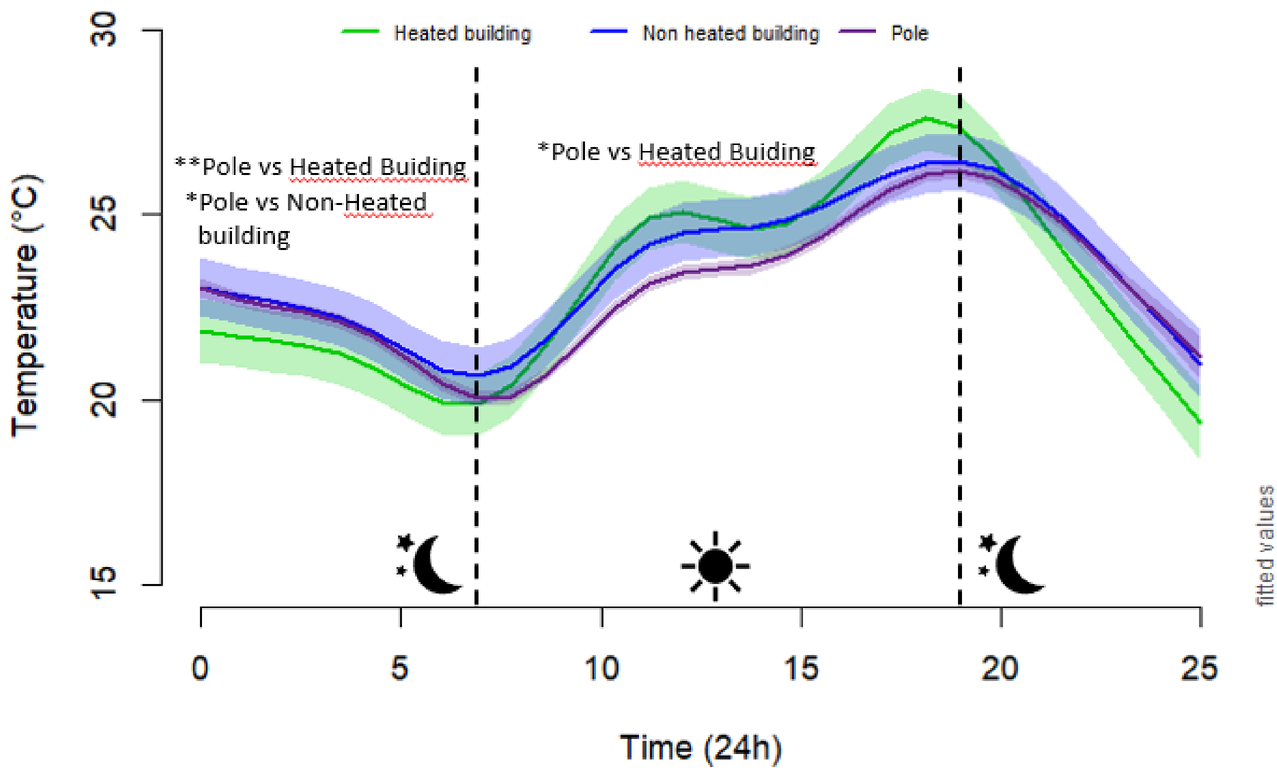
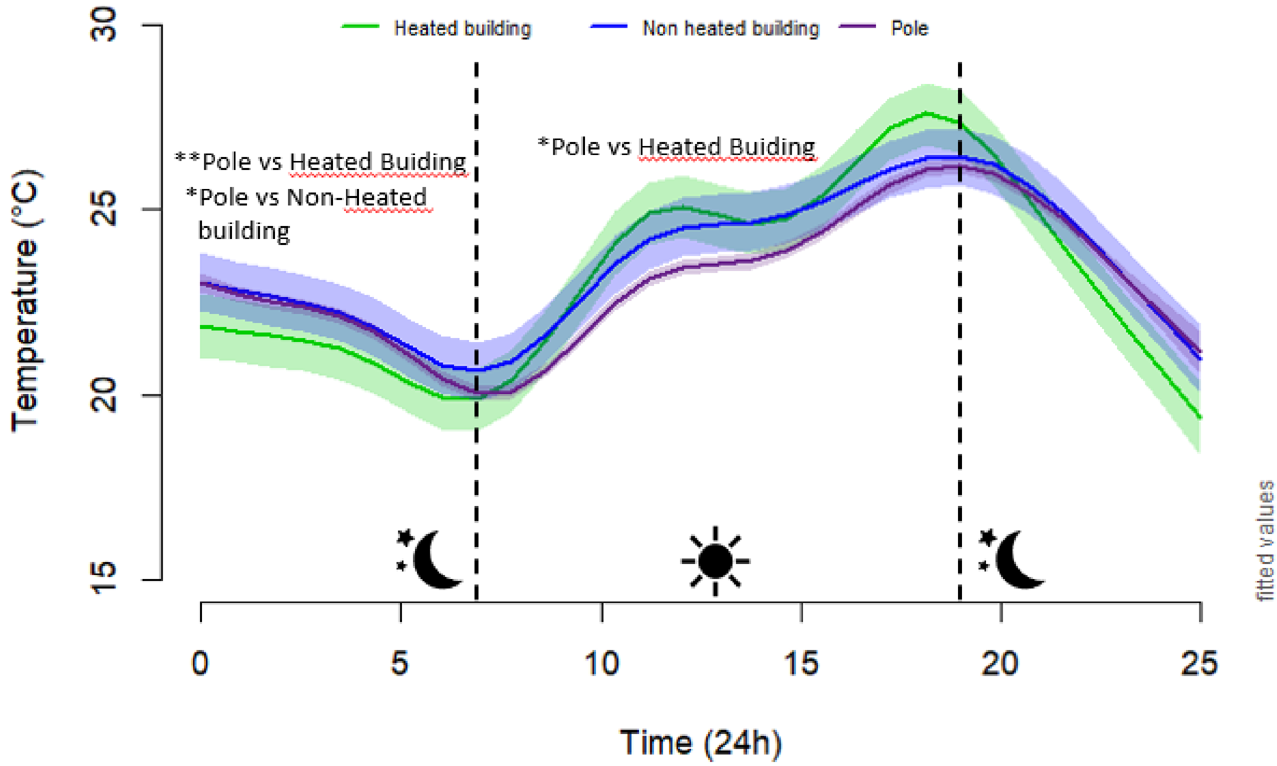


Figure 3

Estimated hourly patterns for the different Classic bat house mountings in Quebec, Canada, in 2017 (pole: n=6, non-heated building: n=6, and heated building: n=6). The estimated values are based on a generalized additive mixed model, accounting for time, date, orientation, external temperature, site, and individual bat house id. Values of fixed factors have been set to: date = July 6, orientation = east, external temperature = 18°C. The asterisks (*) represent significant differences between structures during the day and night. P = pole and B= building.



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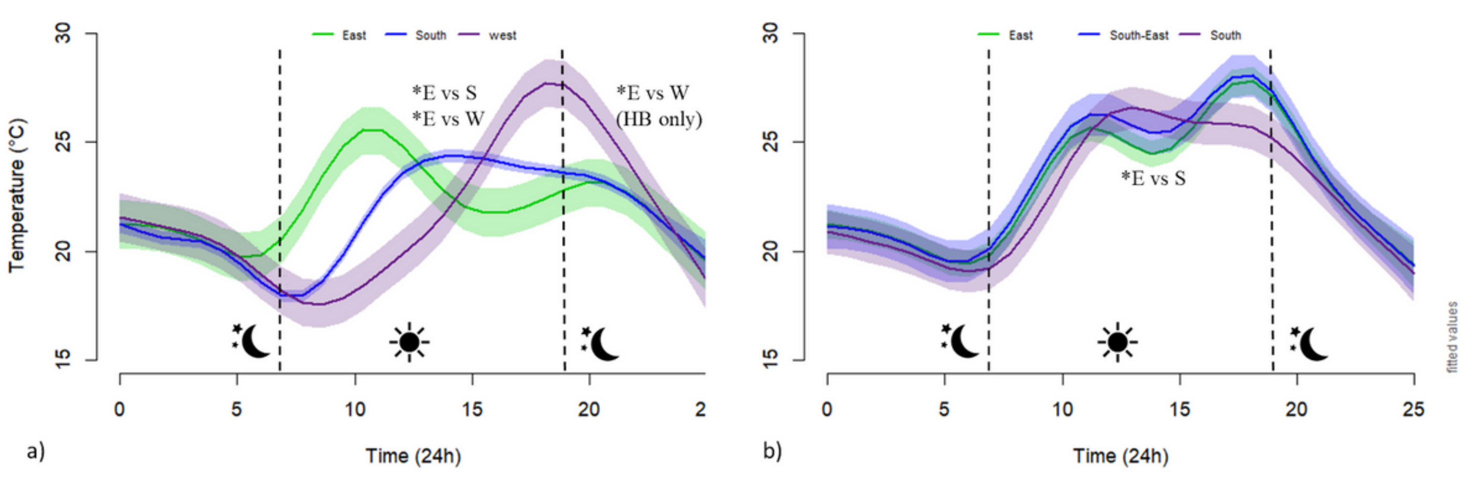
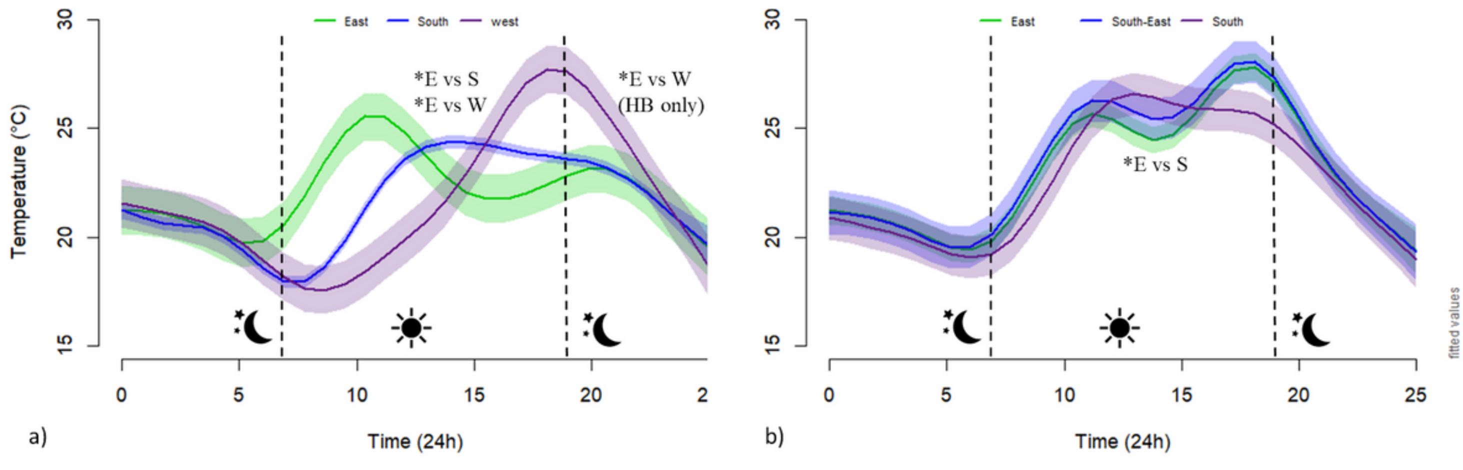


Figure 4

Estimated hourly patterns for the different bat house orientations in Quebec, Canada, in 2017. Bat houses facing east (n=4), south (n-4), and west (n=4) on buildings (a), and facing east (n=2), south (n=2) and south-east (n=2) on poles (b). The estimated values are based on a generalized additive mixed model, accounting for time, date, external temperature, structure, site, and individual bat house id. Values of fixed factors have been set to: date = July 6, external temperature = 18°C. The asterisks (*) represent significant differences between orientations during the day and night. E = east, S = south, W = west, and SE = south-east. HB = heated building.



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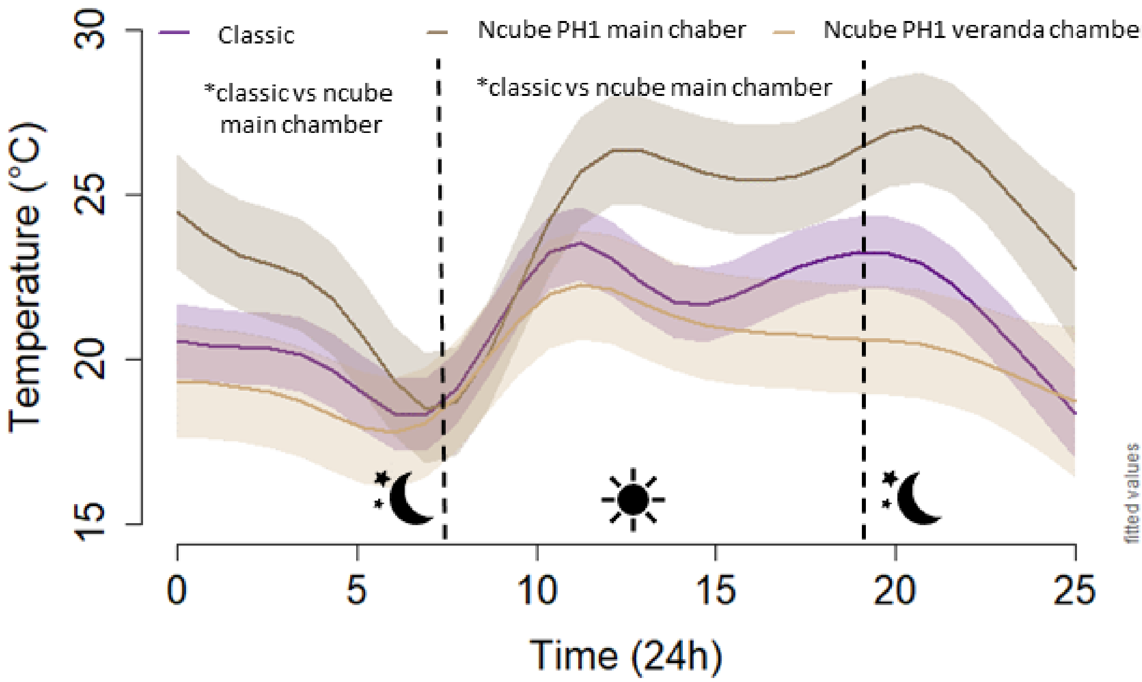
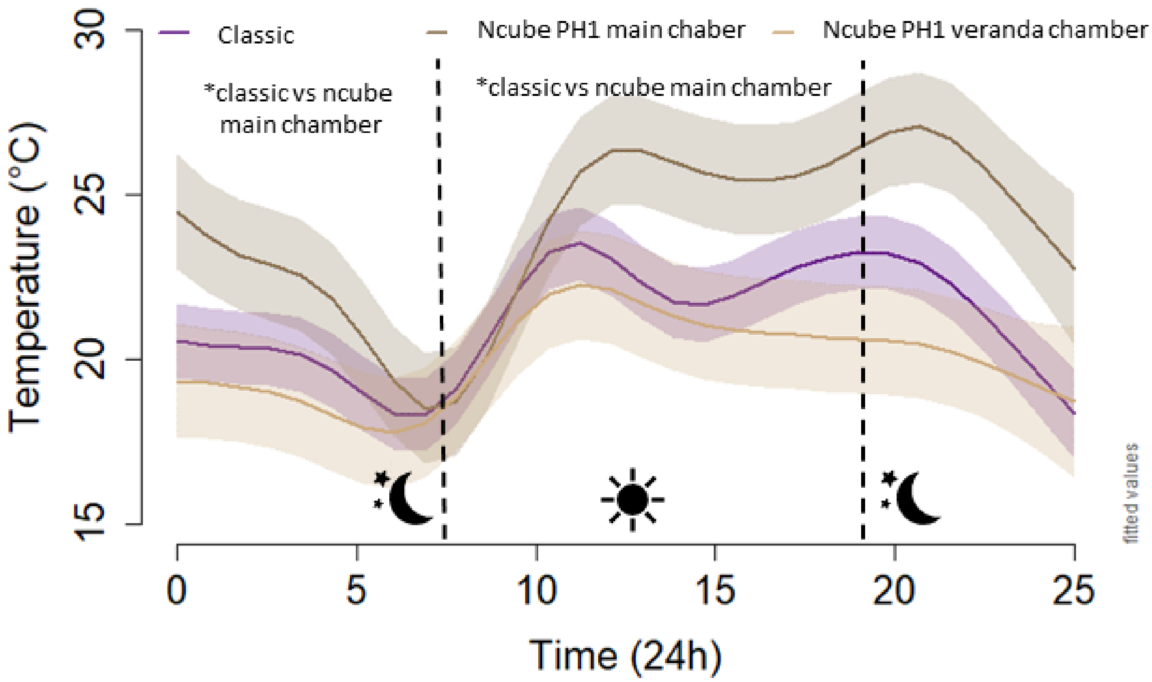


Figure 5

Estimated hourly patterns of the Classic (n=11) and the Ncube PH1 models (main and lower chambers, n=8). The estimated values are based on a generalized additive mixed model accounting for time, week, year, structure, external temperature, site, and individual bat house id. Values of fixed factors have been set to: week = first half of July, year = 2019, structure = building, external temperature = 18°C. The asterisks (*) represent significant differences between models during the day and night.



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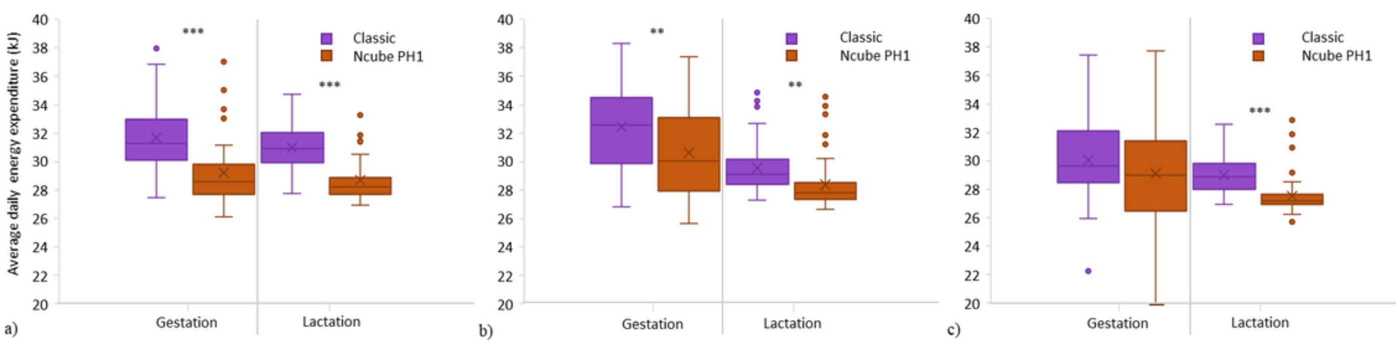
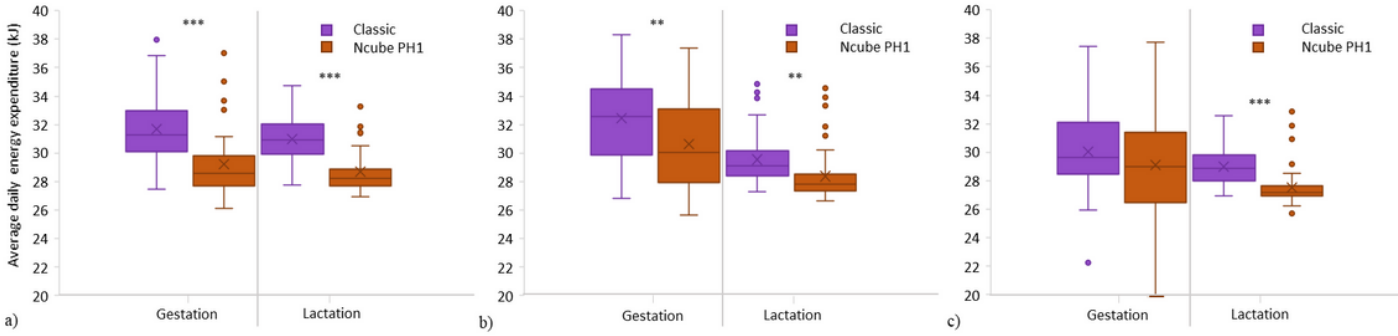


Figure 6

Average daily thermoregulatory energy expenditure (in kilojoules) from bioenergetic modeling for a female bat during the gestation and lactation period in a Classic versus Ncube PH1 2019 bat house on building at: a) cold, b) intermediate, and c) warm sites in Quebec, Canada, in 2019.



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